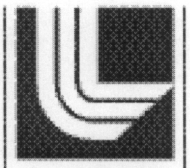

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Long Term Corrosion Potential Behavior of Alloy 22 in Yucca Mountain Relevant Environments

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LONG TERM CORROSION POTENTIAL BEHAVIOR OF ALLOY 22

IN YUCCA MOUNTAIN RELEVANT ENVIRONMENTS

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ABSTRACT

The approach of isolating high-level nuclear waste in the designated site of Yucca Mountain (Nevada) is to separate it from the environment using a series of engineering and natural barriers. The container for the waste will consist of two concentric metal cylinders. The outer cylinder is going to be fabricated of Alloy 22 (N06022). If water is present at the site, several corrosion processes may occur. These include passive or general corrosion, localized corrosion and environmentally assisted cracking. The occurrence of one (or more) mode of corrosion over another will be determined by the redox potential of the aqueous electrolyte that may enter in contact with the container. This redox potential will also control the corrosion potential (E_{corr}) of the container. This paper summarizes the findings of an extensive laboratory testing aimed at measuring E_{corr} of Alloy 22 in presence of a variety of electrolyte solutions. Some of these solutions are multi-ionic electrolytes that may simulate concentrated ground waters. Other environments are chemical solutions of pure salts, which are highly unlikely for an underground repository but that may establish an extreme bounding condition. Current results show that the highest measured potential for Alloy 22 was approximately +0.3 to 0.4 V in the saturated silver chloride [SSC] scale. Most of the E_{corr} values are in the order of 0 V [SSC] or below.

Keywords: high-level nuclear waste, N06022, corrosion potential, temperature, electrolyte composition

INTRODUCTION

The current design for the high-level nuclear waste containers in the USA is based on a metallic multi-barrier system. This design specifies an external layer of Alloy 22 (N06022) and an internal layer of type 316 stainless steel (S31603).[1] The main purpose of the internal barrier is to provide structural integrity and to contribute to the shielding of radiation. The main role of the external barrier is to provide

protection against corrosion. Alloy 22 was selected for the external barrier due to its excellent resistance to general corrosion, localized corrosion and environmentally assisted cracking in a broad range of environments.[2-9] Alloy 22 is a nickel (Ni) based alloy that contains approximately 22% chromium (Cr), 13% molybdenum (Mo), 3% tungsten (W) and 3% iron (Fe). By virtue of its high level of Cr, Alloy 22 remains passive in most industrial environments and therefore has an exceptionally low general corrosion rate. The combined presence of Cr, Mo and W imparts Alloy 22 with high resistance to localized corrosion such as pitting corrosion and crevice corrosion. Mill annealed Alloy 22 is also highly resistant to EAC in acidic concentrated chloride solutions. [7-10] It has been reported that Alloy 22 may suffer EAC in multi-ionic solution; however, EAC was strongly dependent on the solution composition and the applied potential. [10-11] For example, EAC was not found in simulated concentrated water at +0.1 V [SSC]; however, it occurred at +0.4 V [SSC].

From the general and localized corrosion point of view, it is important to know the most probable value of E_{corr} for Alloy 22 under different environmental conditions. The corrosion degradation model for the container assumes that localized corrosion will only occur when E_{corr} is equal or greater than a critical potential (E_{crit}). That is, if $E_{corr} < E_{crit}$, general or passive corrosion will occur. Passive corrosion rates are expected to be exceptionally low. E_{crit} can be defined as a certain potential above which the current density or corrosion rate of Alloy 22 increases significantly and irreversibly above the general corrosion rate of the passive metal. In environments that promote localized corrosion, E_{crit} is the lowest potential that would trigger localized (e.g. crevice) corrosion. The value of E_{crit} cannot be measured as easily as the value of E_{corr} since the value of E_{crit} depends strongly of the method used for its measurement. In every case, the margin of safety against localized corrosion will always be given by the value of $\Delta E = E_{crit} - E_{corr}$.

The container may corrode only if water is present. The climate at Yucca Mountain is dry and water quantities reaching the waste container surface are limited. If water enters in contact with the container, it would be in the form of a multi-ionic solution. This solution may form through two different mechanisms, namely (1) Dripping from the drift wall and concentrating on the container and (2) Deliquescence of salt or mountain dust that may accumulate on top of the container during dry periods. In both cases the solution would be concentrated. The ground waters that are associated with Yucca Mountain have been well characterized. [12-13] The composition of some of the concentrated waters that were investigated are given in Table 1. It is unlikely that pure salt solutions will ever be in contact with the container. That is, pure salt solutions would represent hypothetical extreme bounding conditions.

The purpose of the current work was to investigate the behavior of E_{corr} for mill annealed (MA) Alloy 22 in four multi-ionic environments. Even though it is not envisioned that a pure salt solution would be in contact with the container at the Yucca Mountain site, it was also of interest to investigate the E_{corr} behavior of Alloy 22 in these unlikely bounding conditions.

EXPERIMENTAL TECHNIQUE

The specimens used to assess E_{corr} as a function of immersion time for Alloy 22 were machined from sheet and bar stock. Table 2 shows four typical chemical compositions of some of the heats of Alloy 22 materials used for this study. There were two main group of specimens, (1) Welded U-bend specimens and (2) Untested bar specimens. Approximately half of the U-bend specimens were removed from the Long Term Corrosion Test Facility (LTCTF) and other half U-bend specimens were previously

unexposed. The U-bend specimens were tested in the as-received (AR) or as-machined conditions, which corresponded to a root mean square (RMS) roughness of 32 μ-inch. The U-bend specimens were fabricated from ¾-inch wide and 1/16-inch thick metal strips according to ASTM G 30. The specimens were degreased in acetone and alcohol before testing. During E_{corr} monitoring, the U-bend specimens were fully immersed in the electrolyte of interest. The bar specimens were all previously untested. Bar specimens were ¼-inch in diameter and 12-inch long. They were polished with 600-grit paper and degreased with acetone and alcohol before testing. In all the environments, the E_{corr} of pure platinum rods (ASTM B 561) was also monitored. The platinum rods were 1/8-inch in diameter and 12-inch long. The rods (both Alloy 22 and platinum) were immersed to a depth of 1 inch into the electrolyte solution.

Alloy 22 specimens (Table 3) were designated either DUB or DEA followed by three or four sequential digits. The letter D stands for Alloy 22, the second letter stands for the type of sample, that is, U for U-bend specimen and E for electrochemical (or rod) specimen. The third letter could be either an A (mill annealed or not welded) or B (contains weld material). The labeling of the platinum specimens was the same; however the letter W represented platinum material.

Ten different electrolyte solutions were used in this study. This included four multi-ionic solutions (Table 1) and six simpler solutions. In some solutions, more than one temperature was used for testing. The combination of tests totaled sixteen different conditions or cells (Table 3). The volume of the electrolyte solution in each cell was 2 liters. The electrolyte solutions were naturally aerated; that is, the solutions were not purged, but a stream of air was circulated above the level of the solution. This stream of air exited the vessel through a condenser to avoid evaporation of the electrolyte. The electrochemical potentials in this paper are reported in the silver-silver chloride scale [SSC]. At ambient temperature, the SSC scale is 199 mV more positive than the normal hydrogen electrode (NHE).

EXPERIMENTAL RESULTS AND DISCUSSION

E_{corr} of Alloy 22 in Multi-ionic Simulated Acidified Water (SAW)

There were four cells (vessels) dedicated to the monitoring of E_{corr} for Alloy 22 and platinum in SAW solutions (Cells number 1, 9, 10 and 7N). Table 3 lists the type of samples and their identification, the testing conditions, the value of E_{corr} after one day of testing and on 31 August 2002. For Cell 1 the SAW solution was removed from the LTCTF, that is, it was in contact with other testing coupons for more than four years (1527 days). In Cell 1 there were three specimens; (1) Alloy 22 U-bend (DUB028) which was previously exposed to the LTCTF for 1527 days or 4 years (2) Alloy 22 U-bend (DUB157) that was not tested before (AR) and (3) platinum rod (WEA007). Table 3 and Figure 1 show that E_{corr} for all three specimens in SAW at 60°C changed very little as a function of time. For example, for WEA007 and DUB157, E_{corr} decreased between 30 to 40 mV in approximately 500 days. For DUB028, E_{corr} seemed to start lower than for the other two electrodes; however, Figure 1 shows that after a few days, the E_{corr} of the three electrodes were similar to each other and approximately +0.4 V [SSC]. It can be considered that the testing time for DUB028 was more than 2000 days. This includes 1527 days without the monitoring of E_{corr} in the LTCTF and approximately 500 days in which E_{corr} was monitored in the bench top experiment (Fig. 1). Figure 2 shows a similar behavior of E_{corr} for both Alloy 22 and platinum in SAW at 90°C. The values of E_{corr} in SAW at 90°C (Fig. 2 and Table 3) are in general approximately 0.1 V lower than the values of E_{corr} in SAW at 60°C (Fig. 1).

The values of E_{corr} in SAW (Figs. 1 and 2) for both Alloy 22 and platinum can be considered high and similar to each other. Initially it was assumed that oxidizing cations in the 4-year old LTCTF solution promoted the high anodic value of E_{corr} in Cells 1 and 2 (Figs. 1 and 2). Therefore, another experiment was carried out in Cell 9 in which freshly polished Alloy 22 and platinum rods were exposed to freshly prepared SAW at 90°C (Table 1). Cell 9 contained eight Alloy 22 rods and two platinum rods. Table 3 shows that in day one, the Alloy 22 rods had an average negative potential of –0.152 ± 0.025 V [SSC]. However, after approximately 300 days of testing E_{corr} had increased to a value near 0.4 V [SSC]. The values of E_{corr} for the eight Alloy 22 electrodes were only 1 to 2 mV apart from each other with an average value of 0.388 ± 0.0007V. These are highly reproducible results. Figure 3 shows that this oxidizing steady-state value of E_{corr} was reached in less than 100 days of immersion (Fig. 3 shows the evolution of E_{corr} for only two Alloy 22 electrodes). For the platinum rods, the value of E_{corr} was similar at day one and after approximately 300 days of immersion (Table 3 and Fig. 3). It is also worth pointing out that the values of E_{corr} for the two platinum electrodes after approximately 300 days of testing were only 1 mV apart.

Figure 4 shows the behavior of E_{corr} for freshly polished Alloy 22 and platinum electrodes in the approximately 4.5-year old LTCTF SAW environment at 90°C (Cell 10 in Table 3). Cell 10 contained eight Alloy 22 electrodes and two platinum electrodes. After one day of testing, the average E_{corr} value of the eight Alloy 22 electrodes was 0.213 ± 0.044 V [SSC]. This value (after one day) was more than 350 mV higher than the average value for the electrodes exposed to fresh SAW solution (Cell 9). Figure 4 shows that the E_{corr} for alloy 22 reached the steady state value of approximately 0.350 V [SSC] after only approximately 10 days of testing as compared to the steady state reach for Cell 9 of 100 days. This suggests that the driving force for ennoblement in Cell 10 was higher than the ennoblement driving force in Cell 9.

Results from Figures 1-4 show that the apparent steady state E_{corr} value of Alloy 22 in SAW (an acidic solution) at 60 to 90°C was approximately the same as the one for platinum and in the order of 0.3-0.4 V [SSC]. This high value of E_{corr} is probably due to the formation of a protective chromium rich oxide film on the surface of the Alloy 22 electrodes. The corollary of the tests from Cells 1, 2, 9 and 10 is that, regardless of the starting point of the condition of the metal surface or the age of the electrolyte solution, eventually Alloy 22 undergoes an ennoblement mechanism in SAW. This ennoblement is probably promoted by both the pH value and the presence of nitrate in the solution. The role of each of the components of the solution needs to be investigated further.

Previous studies have shown that the ennoblement of Alloy 22 in SAW is accompanied by a decrease in the passive corrosion rate. [14,15] For example, it was reported that for freshly polished Alloy 22 when E_{corr} was approximately –0.2 V [SSC] in deaerated SAW at 90°C, the corrosion rate was 1140 nm/year. [14] However, after one week in aerated SAW at 90°C, E_{corr} increased to just above 0.3 V [SSC] and the corrosion rate decreased to 103 nm/year. [14]

Table 3 also shows that, the average value of E_{corr} for Alloy 22 in old SAW at ambient temperatures (Cell 7N) was in the order of 0.210 ± 0.012 V [SSC], which was lower than the value average values at 60°C and 90°C. This effect could be attributed to kinetic mechanisms either in the behavior of the oxide film or on the redox reactions in solution.

Multi-ionic acidic solutions such as SAW do not promote localized corrosion in Alloy 22. The increase of current at high anodic potentials is a combination of transpassive dissolution and oxygen evolution by decomposition of water. At 90°C, the value of potential breakdown (corresponding to an arbitrary current density of 20 $\mu A/cm^2$) is in the vicinity of 0.7 V [SSC]. [14,15]

E_{corr} of Alloy 22 in Multi-ionic Alkaline Solutions

Similarly to tests performed above in SAW, E_{corr} was also monitored in Simulated Concentrated Water (SCW) and Simulated Dilute Water (SDW) at 60°C and 90°C and in Basic Saturated Water (BSW) at 105°C (Table 1). SCW and SDW solutions had a pH of approximately 10 and BSW had a pH of approximately 13. E_{corr} values for the alkaline solutions tested in Cells 7, 3, 5, 6 and 4 are given in Table 3. Figure 5 shows the evolution of E_{corr} for SCW and SDW both at 60 and 90°C and Figure 6 shows the evolution of E_{corr} for BSW at 105°C. Figure 5 shows that the steady state values of E_{corr} for Alloy 22 in both SCW and SDW were below 0.1 V [SSC]. The E_{corr} of platinum was also in the same range, except for SDW at 90°C, which was approximately 0.2 V [SSC]. Figure 6 shows that E_{corr} for both platinum and Alloy 22 electrodes in BSW at 105°C was also lower than 0.1 V [SSC]. BSW solution contains a larger amount of nitrate than SAW (Table 1); however, E_{corr} in BSW (Fig. 6) remained low and seemed to be controlled more by the alkaline pH than by the nitrate content.

Multi-ionic alkaline solutions such as SCW, SDW and BSW do not promote localized corrosion in Alloy 22. SCW at near 90°C was found to promote stress corrosion cracking in Alloy 22 at an applied potential of near 0.3 to 0.4 V [SSC]. [11] This detrimental potential is higher than the E_{corr} of 0.1 V (Fig. 5).

E_{corr} of Alloy 22 in $CaCl_2$ and $CaCl_2$ plus $Ca(NO_3)_2$ Solutions

Pure concentrated chloride solutions at temperatures in the order of 90°C are of interest since they may promote localized corrosion such as crevice corrosion in Alloy 22. However, localized corrosion may occur only above a certain threshold potential (E_{crit}), which is expected to be higher than E_{corr} by a margin ΔE. At this moment, values of E_{crit} for Alloy 22 in calcium chloride solutions are being determined and are not part of this paper. Table 3 and Figure 7 show E_{corr} for Alloy 22 and platinum electrodes in 5 M $CaCl_2$ solution at 120°C (Cell 8). At ambient temperature this solution had a pH of 5.21. There were five Alloy 22 electrodes and five platinum electrodes. Figure 7 shows that E_{corr} reached steady state in less than 50 days. The average values of E_{corr} after more than 300 days of testing (Table 3) were -0.129 ± 0.004 V [SSC] for Alloy 22 and 0.492 ± 0.002 V [SSC] for platinum. These are highly reproducible values between each kind of electrode. The negative values of E_{corr} for Alloy 22 seem to suggest that the alloy remained in the active condition in this concentrated 10 M chloride solution at 120°C.

Table 3 and Figures 8-10 show the effect of the addition of nitrate to pure chloride containing solutions (Cells 13-15). Figure 8 shows the evolution of E_{corr} for platinum and Alloy 22 electrodes in 5 M $CaCl_2$ + 0.05 M $Ca(NO_3)_2$ solution at 90°C (Cell 14). This solution represents a chloride over nitrate ratio of 100 [$Cl^-:NO_3^-$ = 100]. Table 3 shows that in Cell 14 there were four Alloy 22 and two platinum electrodes. After approximately 100 days of testing the E_{corr} values for both Alloy 22 and platinum did not seem to have reached a steady state value. E_{corr} seemed to be increasing slowly in time, especially for Alloy 22. However, after 100 days of testing the average value of E_{corr} for Alloy 22 was still low at -

0.039 V ± 0.049 V [SSC]. For the same period, the average E_{corr} for platinum was 0.494 ± 0.008 V [SSC]. Figure 9 shows the evolution of E_{corr} for Alloy 22 and platinum electrodes immersed in 5 M $CaCl_2$ + 0.5 M $Ca(NO_3)_2$ solution at 90°C (Cell 15). At ambient temperature this solution had a pH of 4.75. Cell 15 contained four Alloy 22 electrodes and two platinum electrodes (Table 3). This solution represents a chloride over nitrate ratio of 10 [$Cl^-:NO_3^-$ = 10]. Similarly to the behavior for the $Cl^-:NO_3^-$ = 100 solution, the E_{corr} values for the $Cl^-:NO_3^-$ = 10 solution did not reach steady state values after approximately 100 days of testing. The average E_{corr} values were -0.046 ± 0.036 V [SSC] for Alloy 22 and 0.500 ± 0.005 V [SSC] for platinum. Figure 10 shows the evolution of E_{corr} for Alloy 22 and platinum electrodes immersed in 1 M $CaCl_2$ + 1 M $Ca(NO_3)_2$ solution at 90°C (Cell 13). Cell 13 contained four Alloy 22 electrodes and two platinum electrodes (Table 3). It appears that after 120 days of testing, E_{corr} reached a steady state value for both Alloy 22 and platinum. The average E_{corr} values were 0.168 ± 0.008 V [SSC] for Alloy 22 and 0.488 ± 0.002 V [SSC] for platinum.

The testing temperatures and base chloride concentrations were not the same for Cells 8, 13, 14 and 15, even though the pH was similar and approximately 5. In spite of the variability of parameters between cell and cell, a few correlations could be made on the effect of nitrate. E_{corr} for platinum changed little and without a trend from pure chloride solution ($Cl^-:NO_3^-$ >1000) to ratios of 100, 10 and 1. These values were respectively 0.492, 0.494, 0.500 and 0.488 V [SSC]. However, there seemed to be a trend in the average values of E_{corr} for Alloy 22. It has to be stated again that some of the E_{corr} values for Alloy 22 do not appear to be steady state values. For the high chloride over nitrate ratio (pure chloride solution) E_{corr} for Alloy 22 was –0.129 V [SSC] and for the one to one chloride to nitrate ratio, E_{corr} was almost 300 mV higher at 0.168 V [SSC]. For the intermediate ratios of chloride to nitrate of 100 and 10, E_{corr} values were respectively –0.039 and –0.046 V [SSC]. Longer times of testing are necessary before establishing if this is an actual trend on the values of E_{corr} and what is its relationship between E_{corr} and the amount of nitrate present in the solution.

E_{corr} of Alloy 22 in Oxalic Acid and Sodium Fluoride Solutions

It was important to investigate the E_{corr} behavior of Alloy 22 in organic acids since these acids could be produced by certain species of fungi. Oxalic acid was first selected since it is one of the most aggressive organic acids towards nickel alloys. Figure 11 and Table 3 show the evolution of E_{corr} for Alloy 22 and platinum electrodes in 0.1 M oxalic acid ($C_2O_4H_2$) solution at 30°C (Cell 11). At ambient temperature this solution had a pH of 1.31. Cell 11 had four Alloy 22 electrodes and two platinum electrodes (Table 3). After approximately 180 days of testing, E_{corr} for both Alloy 22 and platinum seemed to have reached steady state values of 0.124 ± 0.008 V [SSC] and 0.445 ± 0.001 V [SSC], respectively. The relatively high value of E_{corr} for Alloy 22 and platinum in oxalic acid solution could be attributed in part to the low pH of the solution and the oxidizing nature of the acid. The above mentioned oxalic acid solutions did not promote localized corrosion in Alloy 22.

Fluoride is present in the ground water at Yucca Mountain; however, its concentration is only in the order of a couple of parts per million (ppm). It was of interest to investigate the E_{corr} behavior of Alloy 22 under extreme bounding conditions of pure concentrated fluoride environments. Figure 11 and Table 3 show the evolution of E_{corr} for Alloy 22 and platinum electrodes in 1 M NaF solution at 90°C (Cell 12). At ambient temperature this solution had a pH of 9.13. After 140 days of testing, E_{corr} for both Alloy 22 and platinum seemed to have reached steady state values of -0.111 ± 0.003 V [SSC] and 0.237 ± 0.001 V [SSC], respectively. The low value of E_{corr} for Alloy 22 and platinum in fluoride solution

could be attributed in part to the higher pH of the solution. A pure fluoride solution was found to be less aggressive towards localized corrosion of Alloy 22 than a pure chloride solution of the same composition.

CONCLUSIONS

(1) E_{corr} of Alloy 22 in naturally aerated Simulated Acidified Water of pH ~ 3 from 60 to 90°C was approximately 0.3 to 0.4 V [SSC]

(2) E_{corr} of Alloy 22 in naturally aerated multi-ionic basic solutions of pH 10-13 from 60 to 105°C was approximately below 0.1 V [SSC]

(3) E_{corr} of Alloy 22 in naturally aerated 5 M $CaCl_2$ solution of pH ~ 5 at 120°C was approximately below –0.1 V [SSC]

(4) Preliminary results show that the presence of nitrate in chloride solutions increased slightly the E_{corr} of Alloy 22.

(5) E_{corr} of Alloy 22 in naturally aerated oxalic acid at 30°C was approximately 0.1 V [SSC} and sodium fluoride solution at 90°C was approximately –0.1 V [SSC].

(6) The highest measured E_{corr} for Alloy 22 was in SAW solution.

(7) Concentrated multi-ionic solutions such as SAW do not promote localized corrosion in Alloy 22.

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TABLE 1
CHEMICAL COMPOSITION OF THE ELECTROLYTE SOLUTIONS (mg/L)

Ion	SDW pH 10.1	SCW pH 10.3	SAW pH 2.8	SSW pH 6.7	BSW pH 13
K^+	34	3400	3400	141,600	81,480
Na^+	409	40,900	40,900	487,000	231,225
Mg^{2+}	1	< 1	1000	---	---
Ca^{2+}	0.5	< 1	1000	---	---
F^-	14	1400	0	---	1616
Cl^-	67	6700	24,250	128,000	169,204
NO_3^-	64	6400	23,000	1,313,000	177,168
SO_4^{2-}	167	16,700	38,600	---	16,907
HCO_3^-	947	70,000	0	---	107,171
SiO_3^{2-}	~ 40	~ 40	~ 40	---	9038

TABLE 2
CHEMICAL COMPOSITION OF THE STUDIED ALLOY 22 HEATS (Wt%)

Element	Single U-bend (Heat 2277-0-3264)	Double U-bend (Heat 2277-8-3203)	Rods DEA 105-109 (Heat 2277-7-3130)	Rods DEA 2797-3090 (Heat 2277-0-3251)
C	0.004	0.002	0.003	0.003
Co	1.14	1.82	0.74	1.21
Cr	21.3	21.30	21.55	21.38
Fe	4.4	4.00	3.54	3.89
Mn	0.29	0.19	0.25	0.23
Mo	13.4	13.08	13.47	13.36
Ni	~56	~57	~57	~57
P	0.01	<0.005	0.007	0.005
S	<0.002	0.008	0.004	0.003
V	0.17	0.14	0.12	0.14
W	2.9	2.93	2.83	2.93

TABLE 3: LIST OF SAMPLES FOR WHICH THE CORROSION POTENTIAL IS BEING MONITORED

Cell	Sample Type and Number	Initial Condition of the Sample	E_{corr} Day 1 [SSC]	E_{corr} 31 Aug 2002 [SSC]
CELL 1: Environment: SAW from LTCTF, 60°C, Starting Date: 13 April 2001				
1	Welded Alloy 22 U-bend DUB028	1527 days (4+ Years) in LTCTF	0.178	0.385
1	Welded Alloy 22 U-bend DUB157	Untested, 600 grit	0.432	0.403
1	Wrought Platinum rod WEA007	Untested, 600 grit	0.461	0.415
CELL 2: Environment: SAW from LTCTF, 90°C, Starting Date: 13 April 2001				
2	Welded Alloy 22 U-bend DUB052	1512 days (4+ Years) in LTCTF	0.386	0.276
2	Welded Alloy 22 U-bend DUB159	Untested, 600 grit	0.362	0.299
2	Wrought Platinum rod WEA006	Untested, 600 grit	0.419	0.383
CELL 7: Environment: SCW from LTCTF, 60°C, Starting Date: 13 April 2001 [A]				
7	Welded Alloy 22 U-bend DUB088	1495 days (4+ Years) in LTCTF	0.070	0.019
7	Welded Alloy 22 U-bend DUB156	Untested, 600 grit	-0.039	-0.014
7	Wrought Platinum rod WEA010	Untested, 600 grit	-0.032	0.032
CELL 3: Environment: SCW from LTCTF, 90°C, Starting Date: 13 April 2001				
3	Welded Alloy 22 U-bend DUB112	1464 days (4+ Years) in LTCTF	-0.027	0.000
3	Welded Alloy 22 U-bend DUB161	Untested, 600 grit	-0.161	-0.061
3	Wrought Platinum rod WEA003	Untested, 600 grit	-0.050	0.069
CELL 5: Environment: SDW from LTCTF, 60°C, Starting Date: 13 April 2001				
5	Welded Alloy 22 U-bend DUB128	1460 days (4+ Years) in LTCTF	0.077	0.025
5	Welded Alloy 22 U-bend DUB150	Untested, 600 grit	-0.082	-0.067
5	Wrought Platinum rod WEA011	Untested, 600 grit	0.179	0.258
CELL 6: Environment: SDW from LTCTF, 90°C, Starting Date: 13 April 2001				

6	Welded Alloy 22 U-bend DUB132	1457 days (4+ Years) in LTCTF	0.032	0.081
6	Welded Alloy 22 U-bend DUB162	Untested, 600 grit	-0.096	0.082
6	Wrought Platinum rod WEA005	Untested, 600 grit	0.138	0.074

CELL 4: Environment: BSW from Bench Top, 105°C, Starting Date: 26 April 2001

4	Wrought Alloy 22 Double U-bend ARC22 U20A + ARC22 U20B	407 days (1+ year) in Bench Top	-0.112	0.046
4	Welded Alloy 22 U-bend DUB163	Untested, 600 grit	-0.754	0.027
4	Wrought Platinum rod WEA014	Untested, 600 grit	0.030	0.074

CELL 8: Environment: 5 M $CaCl_2$, 120°C, Starting Date: 28 September 2001

8	Wrought Alloy 22 Rod DEA105	Untested, 600 grit	-0.324	-0.132
8	Wrought Alloy 22 Rod DEA106	Untested, 600 grit	-0.327	-0.126
8	Wrought Alloy 22 Rod DEA107	Untested, 600 grit	-0.337	-0.135
8	Wrought Alloy 22 Rod DEA108	Untested, 600 grit	-0.342	-0.126
8	Wrought Alloy 22 Rod DEA109	Untested, 600 grit	-0.308	-0.126
8	Wrought Platinum Rod WEA015	Untested, 600 grit	0.382	0.490
8	Wrought Platinum Rod WEA016	Untested, 600 grit	0.388	0.493
8	Wrought Platinum Rod WEA017	Untested, 600 grit	0.389	0.495
8	Wrought Platinum Rod WEA018	Untested, 600 grit	0.413	0.489
8	Wrought Platinum Rod WEA019	Untested, 600 grit	0.391	0.492

CELL 9: Environment: SAW, 90°C, Starting Date: 23 October 2001

9	Wrought Alloy 22 Rod DEA2797	Untested, 600 grit	-0.153	0.389
9	Wrought Alloy 22 Rod DEA2853	Untested, 600 grit	-0.130	0.389
9	Wrought Alloy 22 Rod DEA2881	Untested, 600 grit	-0.116	0.388
9	Wrought Alloy 22 Rod DEA2928	Untested, 600 grit	-0.131	0.389
9	Wrought Alloy 22 Rod DEA2940	Untested, 600 grit	-0.189	0.388
9	Wrought Alloy 22 Rod DEA3010	Untested, 600 grit	-0.172	0.389
9	Wrought Alloy 22 Rod DEA3014	Untested, 600 grit	-0.144	0.387
9	Wrought Alloy 22 Rod DEA3082	Untested, 600 grit	-0.183	0.388
9	Wrought Platinum Rod WEA021	Untested, 600 grit	0.414	0.400
9	Wrought Platinum Rod WEA022	Untested, 600 grit	0.406	0.399

CELL 10: Environment: LTCTF SAW, 90°C, Starting Date: 11 December 2001

10	Wrought Alloy 22 Rod DEA2850	Untested, 600 grit	0.105	0.353
10	Wrought Alloy 22 Rod DEA2851	Untested, 600 grit	0.220	0.345
10	Wrought Alloy 22 Rod DEA2852	Untested, 600 grit	0.213	0.344
10	Wrought Alloy 22 Rod DEA2854	Untested, 600 grit	0.232	0.350
10	Wrought Alloy 22 Rod DEA2855	Untested, 600 grit	0.265	0.351

10	Wrought Alloy 22 Rod DEA2856	Untested, 600 grit	0.239	0.342
10	Wrought Alloy 22 Rod DEA2857	Untested, 600 grit	0.221	0.347
10	Wrought Alloy 22 Rod DEA2858	Untested, 600 grit	0.205	0.347
10	Wrought Platinum Rod WEA025	Untested, 600 grit	0.381	0.347
10	Wrought Platinum Rod WEA026	Untested, 600 grit	0.382	0.348

CELL 7N: Environment: LTCTF SAW, Ambient Temp, Starting Date: 21 December 2001

7N	Wrought Alloy 22 Rod DEA2802	Untested, 600 grit	0.146	0.221
7N	Wrought Alloy 22 Rod DEA2807	Untested, 600 grit	0.151	0.215
7N	Wrought Alloy 22 Rod DEA2859	Untested, 600 grit	0.139	0.194
7N	Wrought Platinum Rod WEA010	Untested, 600 grit	0.387	0.376

CELL 11: Environment: 0.1 M $C_2O_4H_2$, 30°C, Starting Date: 03 March 2002

11	Wrought Alloy 22 Rod DEA2843	Untested, 600 grit	0.112	0.134
11	Wrought Alloy 22 Rod DEA2844	Untested, 600 grit	0.106	0.123
11	Wrought Alloy 22 Rod DEA2845	Untested, 600 grit	0.099	0.113
11	Wrought Alloy 22 Rod DEA2849	Untested, 600 grit	0.108	0.127
11	Wrought Platinum Rod WEA033	Untested, 600 grit	0.530	0.445
11	Wrought Platinum Rod WEA034	Untested, 600 grit	0.518	0.444

CELL 12: Environment: 1 M NaF, 90°C, Starting Date: 10 April 2002

12	Wrought Alloy 22 Rod DEA3083	Untested, 600 grit	-0.167	-0.106
12	Wrought Alloy 22 Rod DEA3084	Untested, 600 grit	-0.165	-0.114
12	Wrought Alloy 22 Rod DEA3085	Untested, 600 grit	-0.164	-0.112
12	Wrought Alloy 22 Rod DEA3086	Untested, 600 grit	-0.162	-0.113
12	Wrought Platinum Rod WEA030	Untested, 600 grit	0.249	0.237
12	Wrought Platinum Rod WEA036	Untested, 600 grit	0.248	0.236

CELL 13: Environment: 1 M $CaCl_2$ + 1 M $Ca(NO_3)_2$, 90°C, Starting Date: 30 April 2002

13	Wrought Alloy 22 Rod DEA3087	Untested, 600 grit	-0.236	0.173
13	Wrought Alloy 22 Rod DEA3088	Untested, 600 grit	-0.231	0.155
13	Wrought Alloy 22 Rod DEA3089	Untested, 600 grit	-0.211	0.177
13	Wrought Alloy 22 Rod DEA3090	Untested, 600 grit	-0.220	0.165
13	Wrought Platinum Rod WEA027	Untested, 600 grit	0.465	0.486
13	Wrought Platinum Rod WEA029	Untested, 600 grit	0.460	0.489

CELL 14: Environment: 5 M $CaCl_2$ + 0.05 M $Ca(NO_3)_2$, 90°C, Starting Date: 21 May 2002

14	Wrought Alloy 22 Rod DEA2800	Untested, 600 grit	-0.219	-0.040
14	Wrought Alloy 22 Rod DEA2801	Untested, 600 grit	-0.218	-0.103

14	Wrought Alloy 22 Rod DEA2803	Untested, 600 grit	-0.242	-0.048
14	Wrought Alloy 22 Rod DEA2804	Untested, 600 grit	-0.204	0.035
14	Wrought Platinum Rod WEA023	Untested, 600 grit	0.398	0.486
14	Wrought Platinum Rod WEA028	Untested, 600 grit	0.427	0.501

CELL 15: Environment: 5 M $CaCl_2$ + 0.5 M $Ca(NO_3)_2$, 90°C, Starting Date: 29 May 2002

15	Wrought Alloy 22 Rod DEA2805	Untested, 600 grit	-0.251	-0.089
15	Wrought Alloy 22 Rod DEA2806	Untested, 600 grit	-0.242	0.007
15	Wrought Alloy 22 Rod DEA2808	Untested, 600 grit	-0.237	-0.036
15	Wrought Alloy 22 Rod DEA2809	Untested, 600 grit	-0.231	-0.067
15	Wrought Platinum Rod WEA008	Untested, 600 grit	0.432	0.505
15	Wrought Platinum Rod WEA024	Untested, 600 grit	0.419	0.496

(A) Test Terminated 18 November 2001.

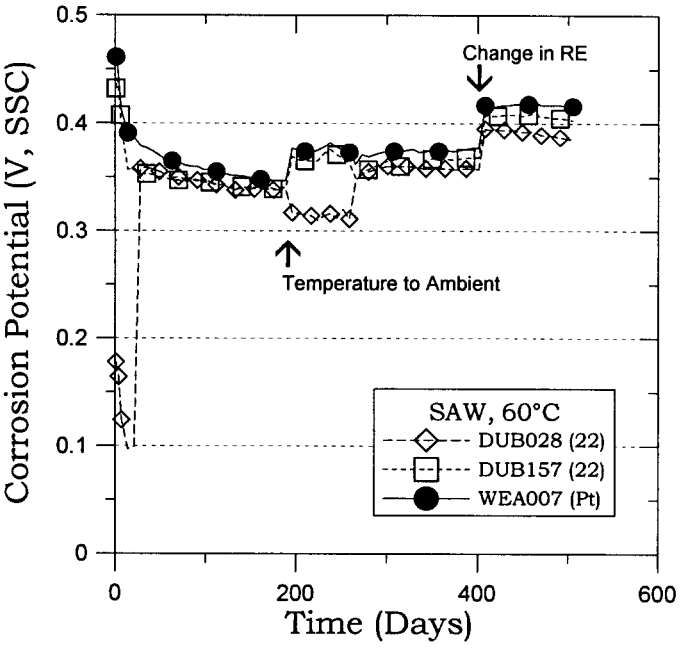

FIGURE 1: E_{corr} for Alloy 22 and Platinum in LTCTF SAW at 60°C (Cell 1 in Table 3).

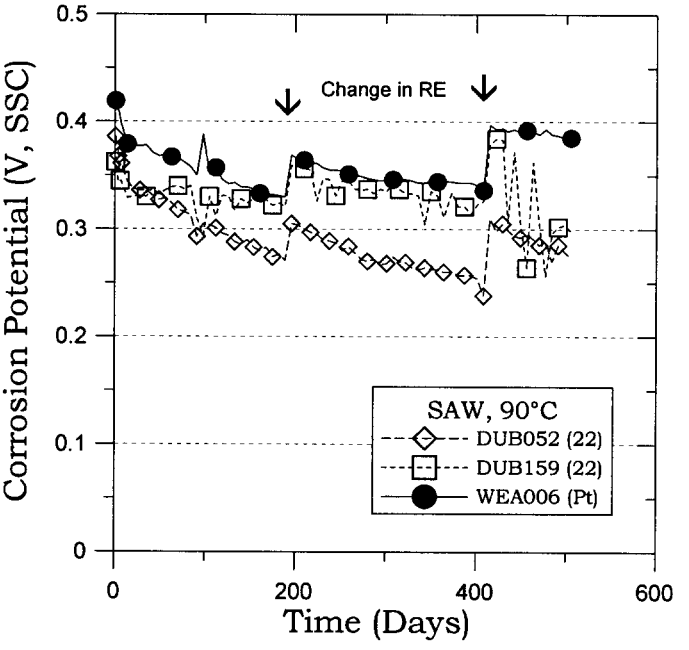

FIGURE 2: E_{corr} for Alloy 22 and Platinum in LTCTF SAW at 90°C (Cell 2 in Table 3).

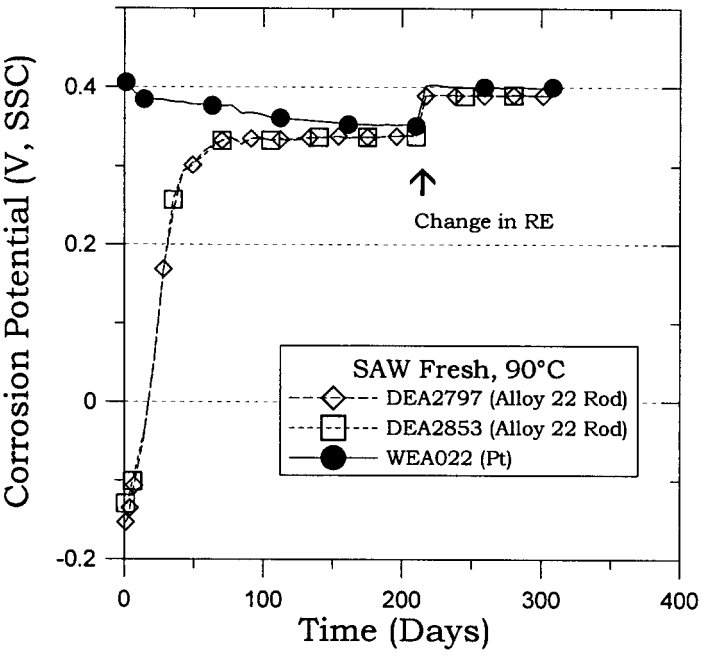

FIGURE 3: E_{corr} for Alloy 22 and Platinum in fresh SAW at 90°C (Cell 9 in Table 3).

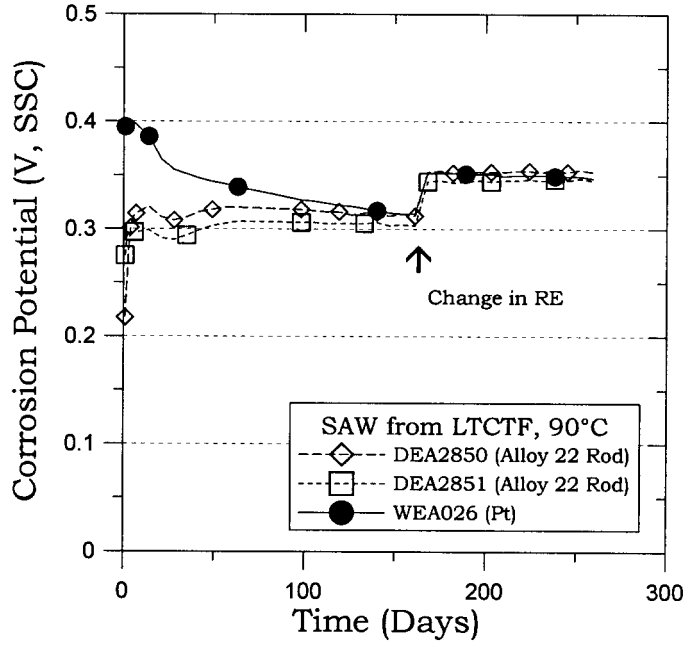

FIGURE 4: E_{corr} for Alloy 22 and Platinum in LTCTF SAW at 90°C (Cell 10 in Table 3).

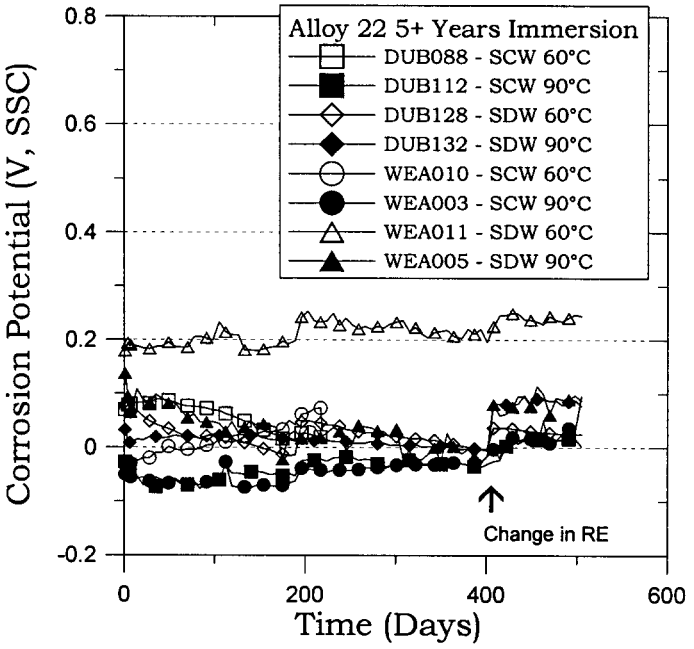

FIGURE 5: E_{corr} for Alloy 22 and Platinum in SCW and SDW at 60°C and 90°C (Cells 7, 3, 5 and 6 in Table 3).

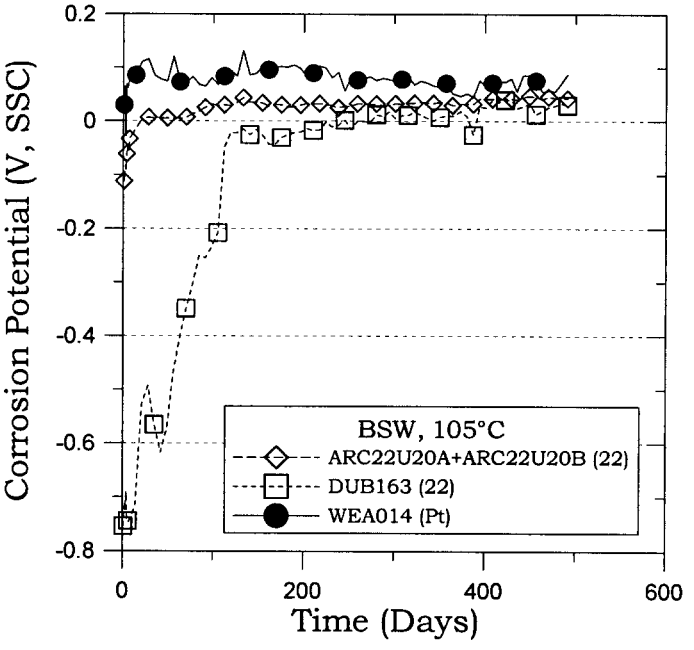

FIGURE 6: E_{corr} for Alloy 22 and Platinum in BSW at 105°C (Cell 4 in Table 3).

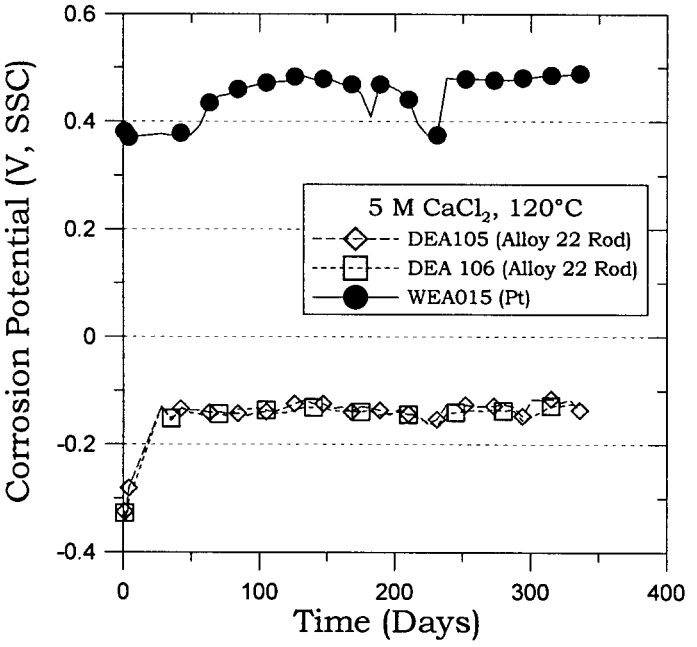

FIGURE 7: E_{corr} for Alloy 22 and Platinum in 5 M $CaCl_2$ at 120°C (Cell 8 in Table 3).

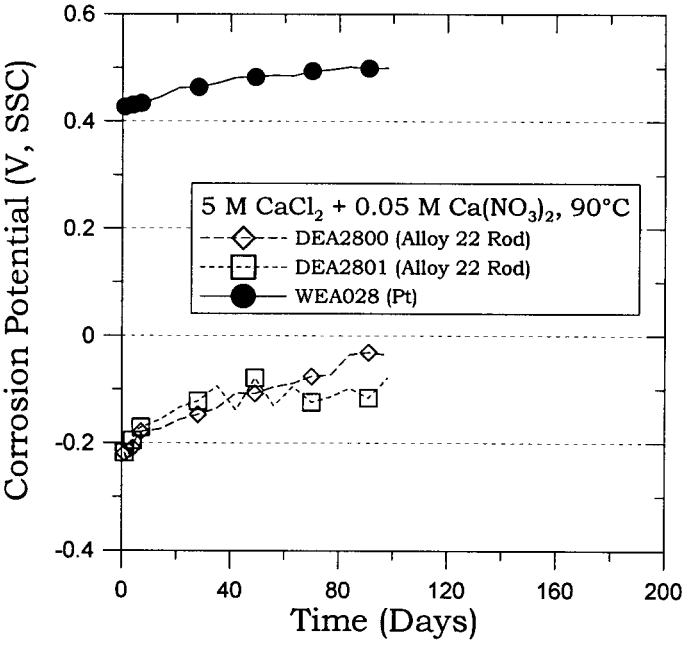

FIGURE 8: E_{corr} for Alloy 22 and Platinum in 5 M $CaCl_2$ + 0.05 M $Ca(NO_3)_2$ at 90°C (Cell 14 in Table 3).

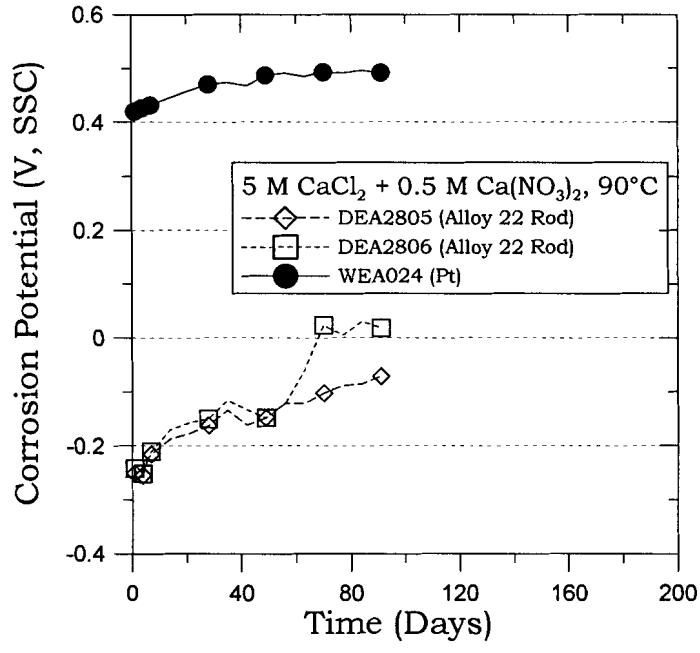

FIGURE 9: E_{corr} for Alloy 22 and Platinum in 5 M $CaCl_2$ + 0.5 M $Ca(NO_3)_2$ at 90°C (Cell 15 in Table 3).

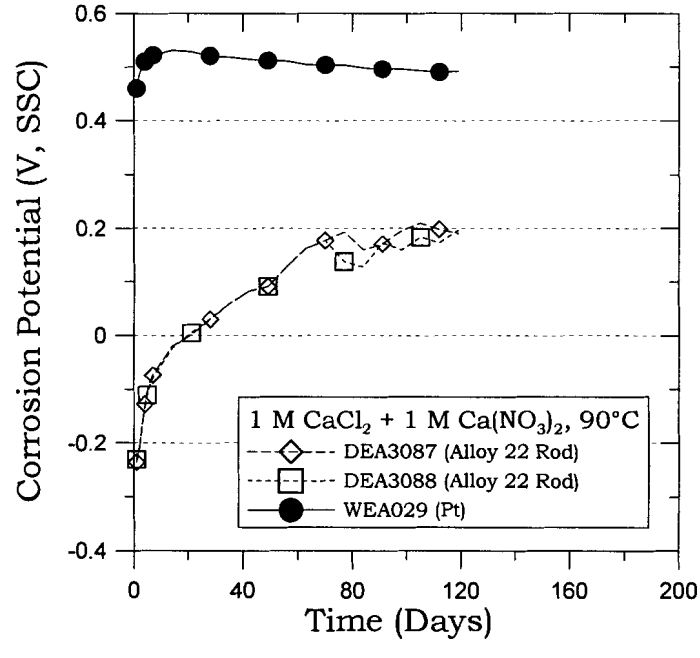

FIGURE 10: E_{corr} for Alloy 22 and Platinum in 1 M $CaCl_2$ + 1 M $Ca(NO_3)_2$ at 90°C (Cell 13 in Table 3).

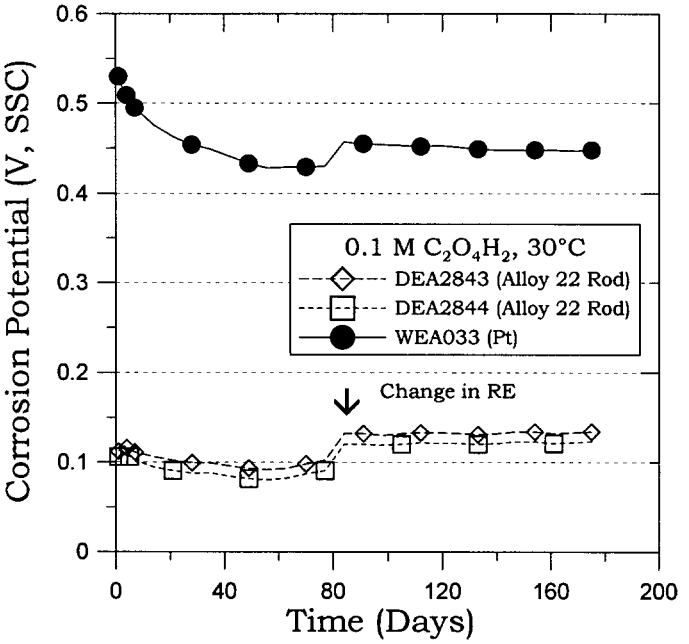

FIGURE 11: E_{corr} for Alloy 22 and Platinum in 0.1 M Oxalic Acid ($C_2O_4H_2$) at 30°C (Cell 11 in Table 3).

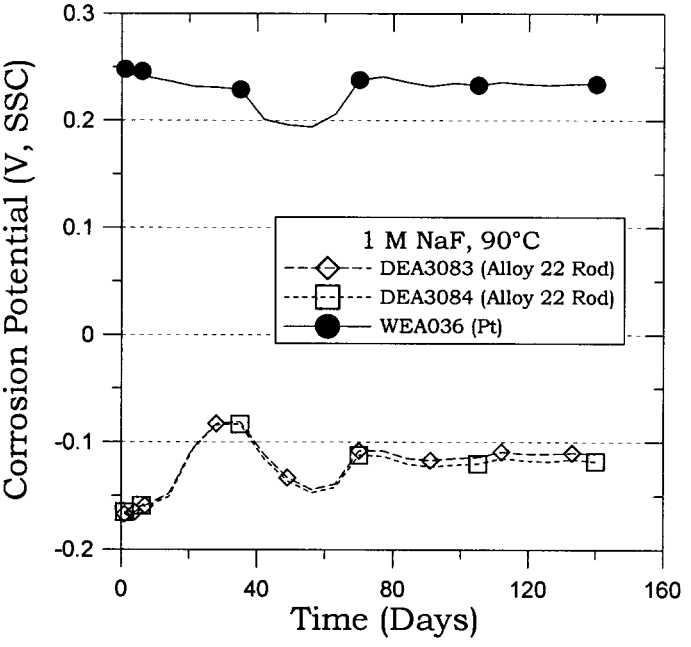

FIGURE 12: E_{corr} for Alloy 22 and Platinum in 1 M NaF at 90°C (Cell 12 in Table 3).